

N94- 25698

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## 1991-1992 PROJECT SUMMARIES

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### Abstract

The Department of Mechanical Engineering at The University of Texas at Austin participated in seven cooperative design projects this year. Six of the projects were associated with the Johnson Space Center and include the design of a thermal control system for an inflatable lunar habitat module, a vibration isolation system for a Space Shuttle cycle ergometer, a radiator shading device for a lunar outpost, a reusable astronaut safety tether, a resistive exercise device for use on the Space Shuttle, and a fleet of autonomous regolith throwing devices for radiation shielding of lunar habitats. The seventh project is associated with the Jet Propulsion Lab and involves the design of a shock absorbing wheel for a small six-wheeled Martian Rover Vehicle.

### DESIGN OF A THERMAL CONTROL SYSTEM FOR AN INFLATABLE LUNAR HABITAT MODULE

NASA is considering the establishment of a manned lunar base within the next few decades. To house and protect the crew from the harsh lunar environment, a habitat is required. A proposed habitat is a spherical, inflatable module. Heat generated in the module must be rejected to maintain a temperature suitable for human habitation. This study presents a conceptual design of a thermal control system for an inflatable lunar module. The design solution includes heat acquisition, heat transport, and heat rejection subsystems.

The study discusses alternative designs and design solutions for each of the three subsystems mentioned above. Alternative subsystems for heat acquisition include a single water-loop, a single air-loop, and a double water-loop. The vapor compression, vapor absorption, and metal hydride adsorption cycles are the three alternative transport subsystems. Alternative rejection subsystems include flat plate radiators, the liquid droplet radiator, and reflux boiler radiators. Feasibility studies on alternatives of each subsystem showed that the single water-loop, the vapor compression cycle, and the reflux boiler radiator were the most feasible alternatives. These three subsystems were combined to create a final design. The mass of the entire system is 4430 kg. The average power consumption is 17 kW.

The heat generated within the module is primarily due to science experiments, communication systems, the life support system, and the thermal control system. It was determined that for a crew of twelve, the maximum heat load generated within the module is 90 kW. To remove this heat, a single water-loop acquisition system was designed. The single water-loop system maintains the module at a temperature range of 18 to 24° C. The humidity is maintained at 50%. The system also meets ventilation requirements by providing five air changes per hour.

The vapor compression cycle used in this design was a two-stage cycle. To remove 90 kW of internal heat, 52 kW of electrical power is required. If a multiple stage operation is used, the system can be operated at lower power during lunar night or when the internal heat load decreases. Using a multiple stage operation, a 52% reduction in average power consumption is attained.

The reflux boiler radiator is an evaporation-condensation device used for transferring and rejecting heat. This radiator consists of a closed tube, with a fixed volume of working fluid. The working fluid is evaporated at the bottom of the tube, and condenses due to gravity along the sides of the tube. During condensation, the heat is transferred through the radiator walls and radiated to the lunar environment.

Due to redundancy requirements, 20 radiators were used. The radiators are rectangular and provide a total surface area of 345 m<sup>2</sup>. The radiators were initially designed to reject the maximum heat load at lunar noon. A control system was then designed to adapt the radiators for lower heat loads and lower sink temperatures. To control the rejection capability of the radiators, the radiator area must be varied. The area of the radiators was varied by both bypassing radiators as well as using the variable conductance concept. The variable conductance concept consists of using an inert gas at the top of a reflux boiler radiator. The inert gas responds to changes in heat loads by expanding or contracting, thus varying the area available for condensation. By using these two methods of control, the radiator rejection capability can be controlled such that the temperature inside the module is maintained within 18 to 24° C.

## **VIBRATION ISOLATION SYSTEM FOR A SPACE SHUTTLE CYCLE ERGOMETER**

Low frequency vibrations generated during exercise using the cycle ergometer onboard the Space Shuttle can disrupt sensitive microgravity experiments. The design team worked with engineers from the Manned Systems Division at the Johnson Space Center to generate alternatives for the design of a vibration isolation system for the cycle ergometer. It is the design team's objective to present alternative designs and a problem solution for a vibration isolation system for an exercise cycle ergometer to be used onboard the space shuttle.

In the development of alternative designs, the design team emphasized passive systems as opposed to active control systems. This decision was made because passive systems are less complex than active control systems, external energy sources are not required, and mass is reduced due to the lack of machinery such as servo motors or compressors typical of active control systems.

Eleven alternative designs were developed by the design team. From these alternatives, three active control systems were included to compare the benefits of active and passive systems. Also included in the alternatives was an isolation system designed by an independent engineer that was acquired late in the project. The eight alternatives using passive isolation systems were narrowed down by selection criteria to four considered to be the most promising by the design team. A feasibility analysis was performed on these four passive isolation systems. Based on the feasibility analysis, a final design solution was chosen and further developed.

The design solution uses spring and damper components attached at four corners of the ergometer base. The design team chose to lower the ergometer's natural frequency by lowering the spring constant of the system as opposed to increasing the overall mass. The design team discovered that the low-frequency ergometer vibrations require very low spring constants to begin attenuation. It was found that for operating frequencies above 4 Hz, acceptable attenuation is possible. For lower frequencies the spring constants become so low that ergometer deflections exceed acceptable limits. From the development of this design, the design team concluded that passive systems are not effective at isolating vibrations for the low frequencies and constraints considered for this project.

Recommendations are made for the design and application of passive isolation systems. These recommendations involve modeling the ergometer system and combining the spring isolation system with an active isolation system. The design team assumed a lumped mass for the cycle and rider with forces and moments acting at the center of mass. Additional research is recommended into the feasibility of a combined active and passive isolator system for the cycle

ergometer. This would allow the passive system to operate at high frequencies and the active system to act only at low frequencies. This would provide the required damping at all frequency ranges.

## **JPL MARS ROVER WHEEL**

The Jet Propulsion Laboratory (JPL) has identified the need for a shock absorbing wheel for a small six-wheeled Martian Rover Vehicle. This wheel must meet requirements of minimum mass, linear radial deflection, and reliability in cryogenic conditions over a five-year lifespan. The diameter of the wheel is 12.7 centimeters. Additionally, axial and tangential deflections must be no more than 10% of the radial value.

The team designed a wheel to meet these criteria by use of finite element and dimensionless parameter analysis. Dimensionless parameter techniques developed by the Waterways Experimental Station were used to choose a wheel width. Due to the complex geometry of the wheel, a finite element model describing its behavior was constructed. This model was then used to develop wheel geometry that gave the deflection ratios specified by JPL. Figure 1 illustrates the configuration of the finite element wheel model.

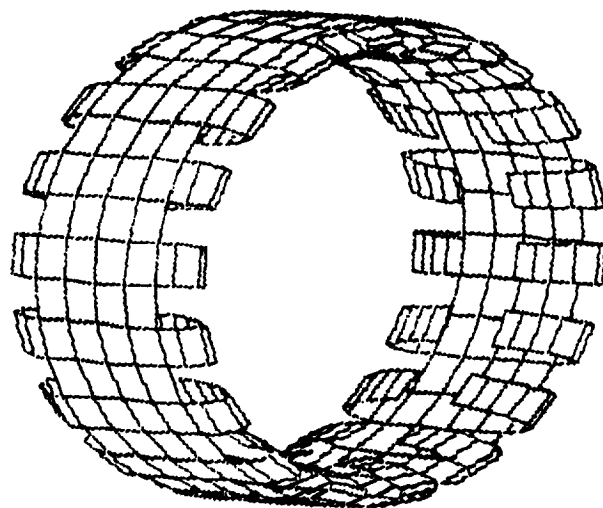


Fig. 1 Finite element model of the Mars rover wheel

A composite material was selected for its high strength, toughness, fatigue resistance, and damping characteristics in the cryogenic conditions. The team chose an aramid fiber-filled thermoplastic composite. Pellethane resin was found to be the most suitable material for this composite application.

## DESIGN OF A RADIATOR SHADING DEVICE FOR A LUNAR OUTPOST

The National Aeronautics and Space Administration is designing a thermal control system for an outpost to be placed permanently on the moon. One of the functions of the thermal control system is to reject waste heat, which can be accomplished through a radiator. At the lunar equator, a radiator may absorb more heat than it rejects during the lunar midday. This problem can be solved either by increasing the temperature of the radiator by means of a heat pump or by reducing the radiation incident on the radiator. The incoming radiation can be reduced by using a shading device that focuses incident solar radiation above the radiator while shading the radiator from other planetary radiation (Figure 2). Two design teams worked with engineers from the Johnson Space Center on design problems associated with this radiator concept.

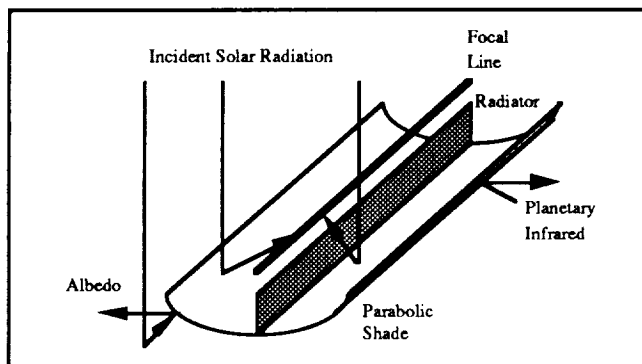


Fig. 2 Parabolic shade configuration

The first design team developed concepts of shading devices for the radiator and for deployment and retraction of the radiator and shade system. Preliminary design of the concepts included support structures, mechanical and thermal stress analyses, and thermal performance. A catenary shaped shade was selected as the most feasible design. In addition, the team developed ideas for removing lunar dust from the shading device.

The second design team designed and built an adjustable catenary shade for simulated lunar environment testing. The simulated lunar environment will be created inside a vacuum chamber at the Johnson Space Center. The shade is remotely adjustable to study the effects of varying focal lengths on the heat rejection problem. The catenary shape closely resembles a parabolic curve for the required aspect ratios. This allows parabolic focal lengths to be used as a basis for design. Figure 3 illustrates the configuration of the catenary shade test fixture.

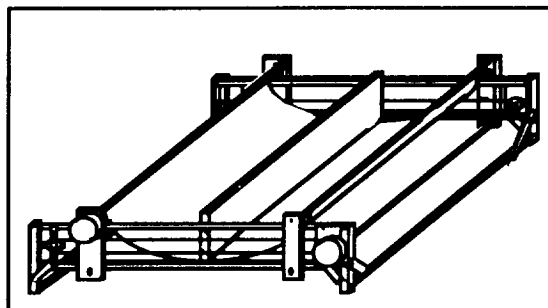


Fig. 3 Adjustable catenary shade test fixture

## REUSABLE ASTRONAUT SAFETY TETHER

The objective of this project was to design a reusable kinetic energy absorber for an astronaut safety tether to be used during extravehicular activities on the Space Station. Currently, the kinetic energy of an astronaut drifting away from the Space Shuttle is absorbed by a safety tether that cannot be reused after it has been deployed. Safety tethers limit the tension in the tether line to prevent damage to the astronaut's space suit or to the structure of the spacecraft. For use on the Space Station, NASA engineers desire a reusable safety device. The device must limit the tension in the tether line, absorb the kinetic energy of a drifting astronaut, signal the astronaut that the safety device has been deployed, and allow resetting after use.

A brainstorming session led to a large number of design concepts using hydraulic, pneumatic, magnetic, electrical, and mechanical methods. The design team selected a constant force spring alternative for further development. The design consists of a pair of constant force springs assembled to make the sum of their forces available at a single point. The springs limit the tension in the tether line and absorb the kinetic energy of the astronaut by uncoiling. A grip roller mechanism prevents recoil of the springs and allows resetting.

The team designed and constructed a prototype of the constant force spring energy absorber. Testing of the prototype confirmed that the device can absorb the kinetic energy and limit the force as required. Recommendations for design improvements were made after testing the prototype. The most critical shortcoming of the prototype is its excessive weight. The springs used in the prototype were made of stainless steel, but they could be made lighter using a composite material. In addition to using lighter composite materials, considerable weight can be reduced by eliminating all but the structurally necessary material from the device.

obtain a maximum launch velocity of 12 m/s, a spring with a maximum compression of 50 cm and a 6.75 kN/m spring constant is used. Each unit has a 200 Watt power requirement.

Three challenging problems were encountered in the design of the device. The first problem is that the scraping method requires a high cutting force. Because the device is lightweight, the traction generated by the device is low. This makes effective scraping difficult to achieve. The second problem with this configuration is that it has a tendency to tip. The tendency to tip is caused by a number of factors including the high acceleration used to launch the regolith, the low device mass, and the high launch position of the regolith with respect to the center of mass of the device. The third problem is the uncertainty of regolith dispersion as it is thrown in the lunar environment.

An impetus for furthering this design project is the versatility of this device. A manned lunar base will require a number of operations which could be performed by this device. An effort must be made throughout the design process to achieve modularity and versatility. A fleet of autonomous devices could perform tasks before the lunar base is established and continue to be of use after astronauts occupy the base.

Incorporated into the design of this device must be an attempt to make it modular so that it may be used for other tasks. One potential use for these devices is to gather regolith for mineral extraction. Regolith contains oxygen and hydrogen. NASA intends to extract the oxygen and hydrogen from the regolith for lunar base use. The regolith throwing devices could be easily modified to gather regolith and throw it into a bin for processing later. Although other methods have been proposed to gather and mine regolith for mineral extraction, modifying the regolith throwing device for this operation makes unnecessary the construction and transportation of another device to the moon.

These devices could also be used for remote surveying of the lunar surface. Because of the automatic operation of these devices, little human operation will be required for this function. This will be of special advantage as it reduces expensive and dangerous extravehicular activity. In addition to remote sensing, these devices could be used as transportation modules to carry small items around the lunar base.

Another possible use for these devices is the clearing of areas for lunar roadways. A previous study recommended that lunar roadways be constructed by clearing the top surface of the lunar regolith and compacting the remaining surface. These devices could be used to clear the roadway rather than transporting a specific device to the moon for this purpose.

The regolith throwing devices could also be modified to excavate craters. Craters will be dug on the lunar surface for the partial burial of lunar habitats and other lunar base buildings. These devices could be programmed to repeatedly clear a certain area of regolith, thus excavating a crater.